The third section of the work deals with wind distribution in the Mediterranean district. Data are included in the tables of this section for a number of countries, including Italy, the Balkans, Palestine, Turkey, and Algiers.

The region of the Tropics is next taken up and discussed under two headings, viz, temperature and wind.

A table of mean temperatures and lapse rates is given for Batavia, and also a table of the average height and temperature of the tropopause for the various months. A table of mean relative humidities for the wet and dry seasons for Batavia shows large differences between these two seasons.

Monthly means of air displacement are given for Batavia for heights up to 24 kilometers, and are based on several hundred observations. Wind data for other regions include central Africa, Honolulu, Samoa, and Mauritius. Mention is also made of Guam, San Juan, and Barranquilla.

The section relating to the Atlantic Ocean is comparatively short, especially that dealing with temperature, little actual data of which are given. However, the important features are mentioned and a few references given. No tables of wind values are given for the Atlantic Ocean, but mean stream lines are shown for winter and summer for the 1–1.5 kilometer and 4–5 kilometer levels.

A good discussion is given of the temperature and wind distribution over India.

Mean monthly and annual temperatures at Agra are shown for heights up to 20 kilometers. The temperature gradients, and the mean heights and temperatures of the tropopause for the various months have also been computed and are given for this station.

Wind data are given for eight stations for three characteristic months, viz, April, August, and December.

Various temperature tables based on kite and sounding balloon observations are given for the region of Spitzbergen and for the base of the British Antarctic expedition of 1911.

The part dealing with winds in the polar regions includes discussions and tables of data for the east and west coast of Greenland, Iceland, the Arctic Ocean, and the Weddell Sea.

The next section of the work deals with isolated sets of observations in the following countries: Egypt, Australia, New Zealand, Japan, Uruguay, and Russian Turkestan.

The part dealing with Egypt contains a table giving free-air pressures, temperatures, and humidities for Helwan. Upper-air wind directions are given for six stations.

The means of a large number of wind observations are given for Australia and New Zealand, and also mean temperatures based on 13 sounding balloon observations.

The means of several hundred wind observations are given for Tateno, Japan, and the means of a lesser number for Montevideo and for Tashkent, in Russian Turkestan.

In the last section the author discusses the free-air temperature and pressure in a meridional section of the Northern Hemisphere. A figure has been drawn to represent the temperature and height of the tropopause along a meridian and with the aid of these temperatures the pressures in a meridional section have been computed. From the pressures a table of pressure gradients was computed and the general circulation discussed with reference to this table.

In this connection it was found that equatorially directed pressure gradients—i. e., lower pressure toward the Equator—occur in the following areas: In summer (1) at the surface between 30° and 10° and again between 90° and 70° latitude; (2) from 6 kilometers up to the greatest heights between 10° and 0°; (3) above 16 kilometers from the Pole to 50° to 40°. In winter (1) in the low levels between the horse latitudes and Equator; (2) above 18 kilometers between 10° and 30° latitude, (3) in the region of the Pole.

Relatively large poleward directed pressure gradients were found in winter at heights of 12 to 18 kilometers, between 0° and 10° latitude. Thus at these heights in winter, west winds theoretically can occur near the Equator. Such winds have been observed in the pilot balloon flights of Batavia.

The maxima pressure gradients were found, at the surface, to be between 50° and 60 ° latitude in summer and between 70° and 80° latitude in winter. In both seasons the maxima are displaced equatorially with increasing height.

THE COLDER THE AIR THE THINNER THE ICE

By W. J. HUMPHREYS

It is a saying among certain Great Lakes fishermen that ice grows faster in zero (Fahrenheit) weather than it does when the temperature is considerably subzero. This, if true, is one of nature's many pleasing puzzles which it always is a delight to solve. But is it true?

Evidently the rate of thickening of the ice (at the under surface, of course) is proportional to the rate of loss of heat by the water up through the ice cover. Under steady conditions this rate in turn is proportional directly to the thermal conductivity of the ice and the difference in temperature between its upper and under surfaces, and indirectly to the thickness of the ice sheet. In other words, it is proportional to the conductivity of the ice and the temperature gradient through it. Now the conductivity of ice is a constant, nearly, if we neglect, or take into account and average, the effect of air bubbles and other irregularities. Also the temperature at the under surface of the ice is a constant, namely, 32° F., in the case of fresh water. We, therefore, can say that for any given thickness of the ice, the rate of its further growth, under steady conditions, is directly proportional to the extent to which the temperature of its outer surface is below the freezing point. That is, it is proportional to $32 - t_s$, in which t_s is the temperature, as indicated by a Fahrenheit thermometer, of the upper surface. If, then, this upper surface always had the temperature of the air above it, there would be no occasion to explain the paradox in question, for there would be no paradox. But this relation does not always hold, and in that fact we have the solution of our fisherman's puzzle.

At temperatures around zero Fahrenheit there is not likely to be much fog drifting over the ice from the open water farther out in the lake, and often too at such times there is wind enough to keep the surface of the ice swept clean of snow. On the other hand, when the temperature of the air is considerably lower the "frost smoke," produced by the "steaming" of the open, deep water and remaining unevaporated at the low temperature, well may spread out slowly over the ice and thereby not only decrease the net loss of heat by radiation, as fogs and clouds always do by the return radiation they themselves give out, but also decrease it, sometimes very greatly, by depositing over the ice an insulating sheet of finely powdered snow. Any substance, even a metal, when finely divided, is a poor conductor of heat, and snow is one of the poorest. Hence ice covered with a layer of fine snow, even though that layer be very thin, loses heat to colder air above much more slowly than it would if bare. Obviously, therefore, under otherwise like conditions ice increases in thickness much faster when bare than it does when snow covered.

Ice of any given thickness grows fastest when its surface is coldest; but this temperature depends in part on the condition of the air above—clear, cloudy, or foggy—and on the condition of its surface, clean or snow covered. And the fog blanket and the fine snow cover are most likely to form in relatively calm and very cold weather, drifted by the gentle movement of the air that commonly obtains on such occasions over and onto the ice sheet to the leeward of the remaining open water.

It well may be, therefore, as fishermen tell us, that at certain places, at least, along the shores of the Great Lakes more ice is formed occasionally, perhaps also on the average, when the temperature of the air is around zero Fahrenheit than there is when that temperature is even 20° to 30° lower, owing, as explained, to the greater prevalence of clear air and clean ice in the first case and foggy air and snowy ice in the second.

But here also, as everywhere and always, a few appropriate figures afford a very necessary check on one's general or qualitative reasoning. Let the conditions be:

a. Temperature of the air −18° C., 0° F., approximately. Thickness of ice, 5, 10, 25, 50 centimeters, respectively. Snow covering, none.

b. Temperature of the air −29° C., −20° F., roughly. Thickness of ice, as in cases *a*. Snow covering, 1 millimeter.

c. Same as *b* in respect to temperature of air and thickness of ice. Snow covering, 5 millimeters.

Now since the radiations of snow and ice at these low temperatures are small; the reflection of sunlight and skylight by snow roughly 90 per cent; the amount of such radiation absorbed by ice also small, especially since there is not likely to be much of it to absorb in midwinter at latitude 47° N., say; and the heat conductivity of ice very low; therefore, as a first approximation, we may assume the temperature of the top surface of the snow or bare ice to be that of the adjacent air. The temperature of the under surface of the ice is, of course, 0° C. Furthermore, as experiment has shown, the conductivity of very loose snow may be as low as one three-hundredths that of ice. Assume it, in the present case, to be one one-hundredth that value, so that as a heat insulator, a layer of our fine snow 1 millimeter deep is the equivalent of a sheet of ice 100 times as thick, 10 centimeters; a 5-millimeter covering of snow the equivalent of a 50-centimeter sheet of ice; and so on for other depths and thicknesses.

In case *a* the difference in temperature between the under and upper surfaces of the ice is 18° C., and in cases *b* and *c* the difference between the temperature of the under surface of the ice and top surface of the snow 29° C. Therefore our various temperature gradients, in terms of centigrade degrees and thicknesses, or equivalent thicknesses, in centimeters, of ice are as given in the following table:

Temperature gradients

Thickness of ice, centimeters	5	10	25	50
Bare; air −18° C	18/5	18/10	18/25	18/50
1 millimeter snow; air −29° C	29/15	29/20	29/35	29/60
5 millimeters snow; air −29° C	29/55	29/60	29/75	29/100

From these gradients it is clear that often bare ice can grow faster when the temperature of the air is 0° F. than can snow-covered ice of the same thickness when the air is much colder, even −20° F. When the thickness of the ice is 16.3 centimeters (6.4 inches) it grows just as fast in 0° F. weather, if bare, as it would with a 1-millimeter covering of loose snow (conductivity of snow one one-hundredth that of ice) in weather at −20° F. If thinner, the bare ice would grow faster than the snow covered at the given temperatures, and if thicker it would grow slower. If the depth of the snow were 5 millimeters the thickness of the ice would need to be 81.8 centimeters (32.2. inches) for the rates of growth under the given conditions to be the same.

In the first of these cases the rate of increase of thickness is about 1 centimeter in four hours, the conductivity of ice being 0.005 (transmitting 0.005 calory per second per square centimeter cross section when the temperature gradient is 1° C. per centimeter), and in the second case 1 centimeter in 20 hours.

Thus the fisherman's interesting paradox, the colder the air the thinner the ice, has become orthodox and lost its fascination.

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